CLAIMS

I/We claim:

[c1] 1. An airfoil, comprising:

an upper surface portion having an upper surface positioned to face generally upwardly during level flight;

a lower surface portion having a leading edge region and a trailing edge region, the lower surface portion further having a lower surface positioned to face generally downwardly during level flight; and

a shock control protrusion extending away from the lower surface, the shock control protrusion being positioned to generate a shock extending away from the lower surface at at least one flight condition.

[c2] 2. The airfoil of claim 1 wherein the lower surface and upper surface are configured for cruise and subsonic Mach numbers.

[c3] 3. The airfoil of claim 1 wherein the shock control protrusion is fixed relative to the lower surface portion of the airfoil.

[c4] 4. The airfoil of claim 1 wherein the shock control protrusion is movable relative to the lower surface portion of the airfoil.

[c5] 5. The airfoil of claim 1 wherein the shock control protrusion includes a plurality of successive segments and, for at least one freestream Mach number, at least some of the successive segments are aligned with characteristic waves generated by the previous segment when the airfoil is flown at the at least one freestream Mach number.

[c6] 6. The airfoil of claim 1 wherein the shock control protrusion includes a plurality of successive segments having generally tangential intersections and, for at least one freestream Mach number, at least some of the successive segments are aligned with characteristic waves generated by the previous segment when the airfoil is flown at the at least one freestream Mach number.

[c7] 7. The airfoil of claim 1 wherein the shock control protrusion has a forward portion smoothly blended with the lower surface at a first location and wherein the shock control protrusion has an aft portion smoothly blended with the lower surface at a second location aft of the first location.

[c8] 8. The airfoil of claim 1 wherein the shock control protrusion includes a single shock control protrusion extending in a generally continuous manner from an inboard location on the lower surface to an outboard location on the lower surface.

[c9] 9. The airfoil of claim 1 wherein the shock control protrusion includes one of a plurality of shock control protrusions extending along an axis from an inboard location on the lower surface to an outboard location on the lower surface.

[c10] 10. The airfoil of claim 1 wherein the lower surface portion has an expected boundary layer thickness at a selected freestream Mach number and airfoil location, and wherein the shock control protrusion is positioned at the airfoil location, with a maximum extent of the shock control protrusion away from the lower surface portion being of the same order as the expected boundary layer thickness.

[c11] 11. The airfoil of claim 1 wherein the upper and lower surface portions include upper and lower surface portions of an aircraft wing.

[c12] 12. The airfoil of claim 1 wherein the shock control protrusion has a chordwise extent in the range of from about 5% to about 25% of a chord length of the airfoil.

[c13] 13. The airfoil of claim 1 wherein the upper and lower surface portions include upper and lower surface portions of a movable aircraft flight control device.

[c14] 14. The airfoil of claim 1 wherein the upper and lower surface portions include upper and lower surface portions of a rotorcraft rotor.

[c15] 15. The airfoil of claim 1 wherein the upper and lower surface portions define a chord length and wherein the shock control protrusion is positioned aft of a leading edge of the airfoil by a distance in the range of from about 20% to about 50% of the chord length.

[c16] 16. The airfoil of claim 1 wherein the shock control profusion includes a first shock control protrusion at a first chordwise location, and wherein the airfoil further comprises a second shock control protrusion at a second chordwise location different than the first chordwise location.

[c17] 17. A transonic airfoil, comprising:

an upper surface portion having an upper surface positioned to face generally upwardly during level flight;

a lower surface portion having a leading edge region and a trailing edge region, the lower surface portion further having a lower surface positioned to face generally downwardly during level flight; and

a plurality of shock control protrusions extending away from the lower surface, with individual shock control protrusions being positioned to

generate a shock extending away from the lower surface at at least one flight condition.

[c18] 18. The airfoil of claim 17 wherein the leading edge region includes a leading edge that is swept along a first axis, and wherein the individual shock control protrusions are aligned along a second axis generally parallel to the first axis.

[c19] 19. The airfoil of claim 17 wherein the individual shock control protrusions are blended with the lower surface, with an edge of the shock control portions being generally tangential to the lower surface.

[c20] 20. The airfoil of claim 17 wherein the shock control protrusions have a generally circular planform shape.

[c21] 21. The airfoil of claim 17 wherein the shock control protrusions are fixed relative to the lower surface.

[c22] 22. The airfoil of claim 17 wherein the shock control protrusions are movable relative to the lower surface.

[c23] 23. A transonic wing, comprising:

an upper surface portion having an upper surface positioned to face generally upwardly during level flight;

a lower surface portion having a leading edge region with a swept leading edge and a trailing edge region aft of the leading edge region, the lower surface portion further having a lower surface positioned to face generally downwardly during level flight; and

at least one shock control protrusion extending away from the lower surface, the at least one shock control protrusion being positioned to

generate a shock extending away from the lower surface at at least one freestream Mach number, the at least one shock control protrusion being fixed relative to the lower surface portion and having a forward portion smoothly blended with the lower surface portion of the airfoil at a first location and an aft portion smoothly blended with the lower surface portion at a second location aft of the first location, and wherein the shock control protrusion includes a plurality of successive segments aligned with characteristic waves generated by the previous segment during flight at the at least one freestream Mach number.

[c24] 24. The airfoil of claim 23 wherein the at least one shock control protrusion includes a single shock control protrusion extending in a generally continuous manner from an inboard location on the lower surface to an outboard location on the lower surface.

[c25] 25. The airfoil of claim 23 wherein the at least one shock control protrusion includes a plurality of shock control protrusions extending along an axis from an inboard location on the lower surface to an outboard location on the lower surface.

[c26] 26. The airfoil of claim 23 wherein the lower surface portion has an expected boundary layer thickness at a selected freestream Mach number and airfoil location, and wherein the at least one shock control protrusion is positioned at the airfoil location, with a maximum extent of the shock control protrusion away from the lower surface portion being of the same order as the expected boundary layer thickness.

[c27] 27. The airfoil of claim 23 wherein the upper and lower surface portions define a chord length and wherein the shock control protrusion is positioned aft of

a leading edge of the airfoil by a distance in the range of from about 20% to about 50% of the chord length.

[c28] 28. An aircraft, comprising:

a fuselage; and

an airfoil coupled to the fuselage, the airfoil including:

an upper surface portion having an upper surface positioned to face generally upwardly during level flight;

a lower surface portion having a leading edge region and a trailing edge region, the lower surface portion further having a lower surface positioned to face generally downwardly during level flight; and

a shock control protrusion extending away from the lower surface, the shock control protrusion being positioned to generate a shock extending away from the lower surface at at least one flight condition.

[c29] 29. The aircraft of claim 28 wherein the airfoil includes a wing.

[c30] 30. The aircraft of claim 28 wherein the airfoil includes at least one of a wing, a horizontal stabilizer, a tail, a rotor, a canard, and a movable flight control surface.

[c31] 31. The airfoil of claim 28 wherein the shock control protrusion is fixed relative to the lower surface portion of the airfoil.

[c32] 32. The airfoil of claim 28 wherein the shock control protrusion includes a plurality of successive segments and, for at least one freestream Mach number, the successive segments are aligned with characteristic waves generated by the

previous segment when the airfoil is flown at the at least one freestream Mach number.

[c33] 33. The airfoil of claim 28 wherein the shock control protrusion includes a single shock control protrusion extending in a generally continuous manner from an inboard location on the lower surface to an outboard location on the lower surface.

[c34] 34. The airfoil of claim 28 wherein the shock control protrusion includes one of a plurality of shock control protrusions extending along an axis from an inboard location on the lower surface to an outboard location on the lower surface.

[c35] 35. A method for controlling airflow over an aircraft airfoil, comprising:

moving an airfoil through an airmass so that a first airstream passes over an upper surface of the airfoil and a second airstream passes over a lower surface of the airfoil, with at least a portion of the second airstream being supersonic; and

controlling a location of a shock in the second airstream by passing the second airstream over a shock control protrusion extending away from the lower surface so that the shock emanates from the protrusion.

[c36] 36. The method of claim 35 wherein moving an airfoil through an airmass includes moving an airfoil having a swept leading edge through an airmass at a subsonic or transonic speed.

[c37] 37. The method of claim 35, further comprising changing at least one of a freestream Mach number and an angle of attack at which the aircraft is flown

while a location at which the shock emanates remains at least approximately stationary.

[c38] 38. The method of claim 35 wherein the airfoil includes first and second generally symmetric airfoil portions positioned on opposite sides of a longitudinal axis of the aircraft, and wherein the method further comprises banking the aircraft while a location at which the shock emanates remains at least approximately stationary.

[c39] 39. The method of claim 35 wherein the airfoil includes first and second generally symmetric airfoil portions positioned on opposite sides of a longitudinal axis of the aircraft, and wherein the method further comprises yawing the aircraft through an angle of at least 2 degrees while a location at which the shock emanates remains at least approximately stationary.

[c40] 40. The method of claim 35, further comprising placing the aircraft in a dive.

[c41] 41. The method of claim 35 wherein passing the second airstream over a shock control protrusion includes passing the second airstream over a plurality of shock control protrusions extending away from the lower surface of the airfoil.

[c42] 42. The method of claim 35 wherein controlling a location of a shock includes controlling a location of the shock to be aft of a leading edge of the airfoil by a distance of from about 20% to about 50% of a chord length of the airfoil.

[c43] 43. A method for making an airfoil, comprising:

forming a lower surface portion of an airfoil having a leading edge region, a trailing edge region, and a lower surface between the leading and trailing edge regions; and

positioning a shock control protrusion to extend away from the lower surface, the shock control protrusion being positioned to generate a shock extending away from the lower surface portion at at least one flight condition.

[c44] 44. The method of claim 43, further comprising attaching the lower surface portion to an upper surface portion.

[c45] 45. The method of claim 43, further comprising forming an upper surface portion of the airfoil simultaneously with forming the lower surface portion of the airfoil.

[c46] 46. The method of claim 43, further comprising sizing the shock control protrusion to extend away from the lower surface by a distance that is on the same order as an expected boundary layer thickness at a selected freestream Mach number.

[c47] 47. The method of claim 43, further comprising:

determining an expected boundary layer thickness at a selected location on the lower surface of the airfoil at a selected Mach number; and

sizing the shock control protrusion to extend away from the lower surface by a distance that is on the same order as the boundary layer thickness.

[c48] 48. The method of claim 43, further comprising providing the shock control protrusion with a plurality of successive segments aligned with characteristic waves generated by the previous segment during flight at the at least one freestream Mach number.